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THE DISTANCE TO THE TYPE Ia SUPERNOVA 1972E AND ITS PARENT GALAXY NGC 5253: A PREDICTION

David Branch, Adam Fisher, Tibor J. Herczeg, Douglas L. Miller, and Peter Nugent
Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019
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ABSTRACT

Sandage et al. have used the *HST* to obtain a Cepheid-based distance to IC 4182, the parent galaxy of the Type Ia SN 1937C, and intend to do the same for NGC 5253, the parent galaxy of the Type Ia SN 1972E. In an attempt to test the predictive power of Type Ia supernovae as distance indicators, we compare the observational properties of SNs 1937C and 1972E and consider the possibility of intrinsic differences between them. A naive application of a relation between absolute magnitude and postpeak decline rate implies that SN 1972E was intrinsically brighter than SN 1937C and at a distance of 5.2 ± 0.6 Mpc. However, because SNs 1937C and 1972E were spectroscopically normal we expect their absolute magnitudes to have been similar and the NGC 5253 distance to be 4.4 ± 0.4 Mpc.

Subject headings: distance scale — galaxies: individual (IC 4182, NGC 5253) — supernovae: general — supernovae: individual (SN 1937C, SN 1972E, SN 1895B)

1. INTRODUCTION

Sandage et al. (1992) have used the *Hubble Space Telescope* to discover 27 Cepheid variables in the nearby Sdm galaxy IC 4182, the parent galaxy of the Type Ia supernova 1937C. The Cepheid period-luminosity relation in both the V and the I bands gives a reddening-free distance modulus of $\mu = 28.36 \pm 0.09$ ($D = 4.7 \pm 0.2$ Mpc), and the apparent magnitude of SN 1937C at maximum light, $V = 8.64 \pm 0.10$, then corresponds to an absolute magnitude $M_V = -19.72 \pm 0.13$ (Saha et al. 1994). This absolute magnitude for SN 1937C is consistent with an independent estimate of the characteristic absolute magnitude of spectroscopically normal SNs Ia obtained on the assumptions that they are thermonuclear disruptions of carbon-oxygen white dwarfs near the Chandrasekhar mass and that their light curves are powered by the radioactive decay of ^{56}Ni and ^{56}Co (Branch 1992). When the Cepheid-based absolute magnitude of SN 1937C is used to calibrate the Hubble diagram for more remote, spectroscopically normal, essentially unextinguished SNs Ia, a Hubble constant near 50 km s^{-1} Mpc^{-1} is obtained (Sandage et al. 1992; Branch & Miller 1993; Sandage & Tammann 1993).

The low value of H_0 thus obtained from SNs Ia conflicts with higher values that are found from other methods such as the Tully-Fisher relation, planetary nebula luminosity functions, and galaxy surface brightness fluctuations (see Jacoby et al. 1992 and Fukugita, Hogan, & Peebles 1993 for reviews and references). The conflict has led to suggestions that SN 1937C may have been an exceptionally luminous event and that the remote SNs Ia may be less luminous explosions of sub-Chandrasekhar-mass white dwarfs (e.g., Fukugita et al. 1993). A direct (but not easy) way to test this conjecture is to determine Cepheid distances to additional SN Ia parent galaxies. Sandage et al. (1992) state their intention to use the *HST* to search next for Cepheids in NGC 5253, the parent galaxy of the Type Ia SN 1972E. In an attempt to test the predictive power of SNs Ia as distance indicators, in this *Letter* we compare the observed properties of SN 1972E and SN 1937C and, taking into account that real physical differences are being detected even among, spectroscopically normal SNs Ia (Branch & van den Bergh 1993; Phillips 1993; Branch, Fisher, & Nugent 1993), we predict the distance to SN 1972E and NGC 5253.

2. SUPERNOVA 1895B IN NGC 5253

Before comparing SNs 1972E and 1937C, we should briefly discuss an earlier supernova in NGC 5253, SN 1895B. The only known photographic spectrum of SN 1895B (Johnson 1936) covers the range 3900–5000 Å and appears to be that of a postmaximum Type Ia supernova. Caldwell & Phillips (1989) review visual descriptions of spectra observed at later phases and conclude that they too support a Type Ia classification for SN 1895B. The shape of the photographic light curve of SN 1895B, covering 400 days beginning at maximum light, also appears to be that of a Type Ia (Leibundgut et al. 1991).

The only obstacle to accepting SN 1895B as a normal Type Ia is that at first glance it appears to have been brighter than SN 1972E. Leibundgut et al. (1991) fit a template Type Ia light curve to all available photometric data for SN 1895B including several individual measurements near the light curve maximum by various observers, and derive a peak apparent photographic magnitude $m_{pg} = 7.0$. The standard relation between m_{pg} and B magnitude for SNs Ia at maximum light, $B = m_{pg} + 0.3$ (Hamuy et al. 1991), then gives $B = 7.3$ for SN 1895B, while by fitting the B light curve of SN 1972E to a template Leibundgut et al. obtain $B = 8.58$ for SN 1972E. Extinction of both supernovae in NGC 5253 probably was small (Caldwell & Phillips 1989), and SN 1972E, at $\sim 100''$ from the center of the galaxy, is even less likely than SN 1895B, at $25''$ from the center, to have been extinguished. The discrepancy appears to be due to the fact that in addition to the definitive m_{pg} light curve for SN 1895B published by Walker (1923), Leibundgut et al. also plot individual magnitude estimates of $m_{pg} = 7.1$ (Fleming & Pickering 1895) and $m_{pg} = 7.5$ (Cannon 1916), even though Walker's light curve includes revised estimates of those two magnitudes. Walker's peak apparent magnitude of $m_{pg} = 8.0$ transforms to $B = 8.3$ which is not inconsistent with $B = 8.58$ for SN 1972E. Thus we think that all available data are consistent with SN 1895B having been a normal Type Ia supernova, but in the next section we will base our estimate of the distance to NGC 5253 solely on SN 1972E.

3. COMPARISON OF SNs 1972E AND 1937C

3.1. *Similarities*

Both SN 1937C and SN 1972E figured prominently in the historical development of SN Ia spectroscopy. In classic papers, Minkowski (1939) presented 25 photographic spectra of SN 1937C that he obtained from 8 to 339 days after maximum light, and Minkowski (1940) divided supernovae into Types I and II with SN 1937C as the prototype of the "extremely homogeneous" Type I class. An approximate relative intensity calibration of some of the SN 1937C spectra was provided later by Greenstein & Minkowski (1973). When Kirshner et al. (1973) began the modern era of linear-detector supernova spectroscopy with their spectral scans of SN 1972E, they made a "very detailed comparison" of SNs 1937C and 1972E and found the two series of spectra to be "almost identical." In a review article Oke & Searle (1974) wrote "The supernova 1937C (IC 4182) has always been used to define what is meant by Type I. This is appropriate.... A comparison [of SNs 1937C and 1972E] reveals that not only were the spectra essentially identical, but also that the rate of change of the spectrum with time was identical. Therefore SN 1937C and 1972E together serve to define precisely what is meant by a Type I supernova. Comparisons of other spectra of Type I ... with these two standard objects reveal that they also adhere closely to the standard pattern." The resolution of the Kirshner et al. spectral scans of SN 1972E ranged from 20 to 80 Å; a few higher resolution spectra were published by Branch & Tull (1978). Later, when the well-observed SN 1981B became the new SN Ia spectral standard, its spectral development was described as "nearly identical" to that of SN 1972E (Branch et al. 1983). In a recent paper on the relative frequencies of spectroscopically normal and peculiar SNs Ia (Branch et al. 1993), both SN 1972E and 1937C are found to have been normal.

The light curves of SNs 1937C and 1972E also were very similar, and normal for Type Ia. This is well illustrated by Leibundgut et al. (1991), who fit observations of SNs 1937C, 1972E, and many others to template Type Ia light curves. The m_{pg} and V light curves of SN 1937C match the templates closely, as do the U, B, and V light curves of SN 1972E. (The m_{pg} light curve of SN 1972E does deviate from the template, but the excellent agreement of the B light curve with its template strongly suggests that the m_{pg} light curve is affected by systematic error.)

Given the similarity of the spectra and light curves of SNs 1937C and 1972E, a first estimate of the difference in their distance moduli is given simply by the difference in their peak apparent magnitudes, appropriately corrected for extinction. The comparison is best carried out in the V band, where both supernovae have good light curves. For SN 1937C, the Leibundgut et al. (1991) fit to the Type Ia template gives $V = 8.55$, but transferral of Beyer's (1939) visual photometry into the modern system by means of subsequent photometry in the IC 4182 field gives $V = 8.64 \pm 0.10$ (Saha et al. 1994), which we adopt. It should be mentioned here that although the only visual photometry plotted by Leibundgut et al. (1991) for SN 1937C is that of Beyer (1939), Parenago (1949) gives a composite visual light curve which includes his own data in addition to that of Beyer; Parenago's data and Beyer's are in excellent agreement. The foreground extinction of IC 4182, at Galactic latitude 79°, is negligible (Burstein & Heiles 1984), as was, evidently, the extinction of SN 1937C within IC 4182 (Saha et al. 1994). For SN 1937C the Leibundgut et al. (1991) fit to a template gives $V = 8.60$. Assuming that the foreground extinction of NGC 5253, at Galactic latitude 30°, is $A_V = 0.09$ (Burstein & Heiles 1984), and that the extinction of SN 1972E within NGC 5253 was negligible, we adopt $V = 8.51 \pm 0.10$ as the extinction-free peak apparent magnitude of SN 1972E. Then SN 1972E was 0.13 ± 0.14 mag brighter than SN 1937C, and on the assumption that their absolute magnitudes were identical, the predicted distance modulus for SN 1972E is $\mu = 28.23 \pm 0.17$ ($D = 4.4 \pm 0.4$ Mpc).

3.2. *Differences?*

In spite of the highly homogeneous nature of spectroscopically normal SNs Ia, some intrinsic differences among them are detectable. A difference that is relatively easy to measure is the wavelength of the deep, nearly unblended, blueshifted absorption feature near 6150 Å due to Si II λ6355. Branch & van den Bergh (1993, hereafter BvdB) find a correlation between the Si II blueshift at 10 days past maximum light and the morphology of the parent galaxy, which demonstrates that the Si II blueshifts reflect global physical differences among SNs Ia rather than just shape asymmetries or clumping in the ejecta. As BvdB discuss, the Si II blueshift is expected to be quite sensitive to explosion strength, with stronger explosions producing larger Si II blueshifts, except in an exceptional case such as SN 1991T that lacked a high Si II blueshift because its high-velocity layers had been burned beyond silicon to iron-peak elements. Nevertheless, although peculiar subluminous SNs Ia such as 1991bg and 1986G do have low Si II blueshifts, no correlation between M_V and Si II blueshift among bright SNs Ia has been demonstrated. In any case, for SNs 1937C and 1972E, BvdB give Si II blueshifts at 10 days past maximum of 10,000 and 10,700 km s^{-1}, respectively; the difference is practically within the measurement errors and is quite small compared to the range of blueshifts, from 8200 to 13,600 km s^{-1}, that BvdB list for a sample of 33 SNs Ia, so no absolute magnitude difference between SNe 1937C and 1972E is implied.

For a sample of nine particularly well observed SNs Ia, Phillips (1993) finds a correlation between peak absolute magnitude and a parameter, Δm_{15}, that measures the decline of the B light curve in magnitudes during the first 15 days after maximum light. The correlation is in the same sense as suggested by Pskovskii (1977, 1984) using a parameter, β, measuring the slope of the linear postpeak decline of the light curve in magnitudes per 100 days. The small sample of nine SNs Ia used by Phillips includes four of the most spectroscopically peculiar SNs Ia: 1991bg, 1986G, 1971I, and 1991T (Branch et al. 1993). SNs 1991bg, 1986G, and 1971I appear to have been weak explosions that to some extent shared the same peculiarities while 1991T was peculiar in its own way. The significance of the correlation between absolute magnitude and Δm_{15} seen by Phillips depends heavily on the inclusion of these peculiar supernovae, but he and Branch et al. (1993) cite evidence that the correlation may hold even among the normal SNs Ia. Therefore we need to check on possible differences in the light-curve decline rates of SNs 1937C and 1972E. The decline rates in B cannot be compared directly because SN 1937C was observed in m_{pg}, not B, but we can compare the visual light curves. Although the Δm_{15} parameter of Phillips is serviceable for supernovae that were well observed over the peak of the light curve, the β parameter is a better choice for supernovae

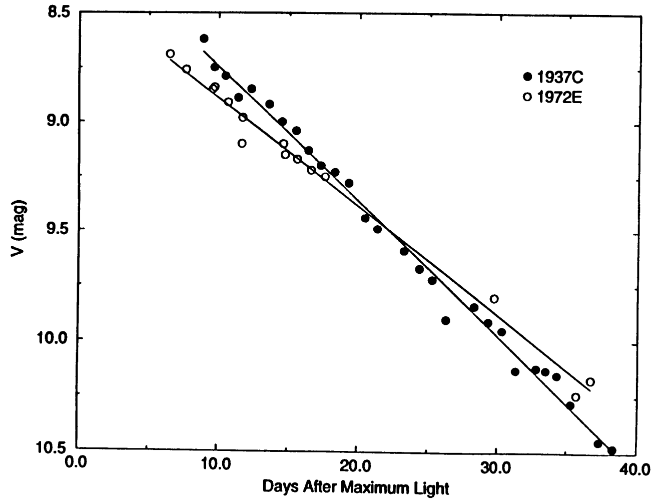

FIG. 1.—Immediate postpeak visual light curve of SN 1937C (Parenago 1949) is compared to the V-band light curve of SN 1972E (Lee et al. 1972; Ardeberg & de Groot 1973). Straight lines correspond to light-curve decline parameters $\beta_V = 6.1$ for SN 1937C and $\beta_V = 5.0$ for SN 1972E.

such as SNs 1972E and 1937C that were well observed during the postpeak decline but not especially so right at the peak. Taking the visual magnitudes of Parenago (1949) for SN 1937C and the V-band photometry of Lee et al. (1972) and Ardeberg & de Groot (1973) for SN 1972E at face value, we find that SN 1937C declined somewhat faster than SN 1972E, with β_V being 6.1 ± 0.3 for SN 1937C as opposed to 5.0 ± 0.3 for SN 1972E (Fig. 1). In order to use this β_V difference to predict an absolute magnitude difference, we have measured β_V for eight of the nine SNs Ia considered by Phillips (1993). Figure 2 shows that for this sample M_V depends linearly on β_V, with a slope $dM_V/d\beta_V = 0.32 \pm 0.03$. SN 1937C, with $\beta_V = 6.1$, falls near the middle of the range for spectroscopically normal

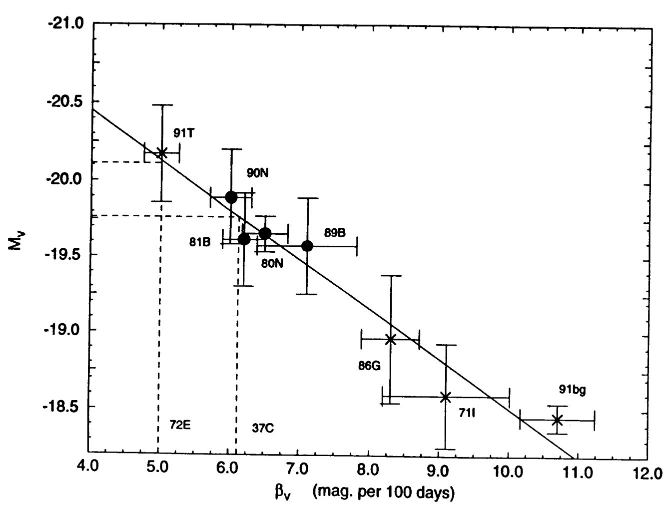

FIG. 2.—Absolute visual magnitude is plotted against light-curve decline parameter β_V for eight SNs Ia from the sample of Phillips (1993). Those having peculiar optical spectra are plotted as crosses. Absolute magnitudes and their uncertainties are from Phillips, but scaled such that $\beta_V = 6.1$ corresponds to the Cepheid-based absolute magnitude of SN 1937C, $M_V = -19.72$. Uncertainties in β_V are taken to be 10% for SNs 1971I and 1989B and 5% for the others. The straight line has a slope $dM_V/d\beta_V = 0.32 \pm 0.03$, so the difference of 1.1 in the β_V values of SNs 1937C and 1972E corresponds to a difference of 0.35 in M_V.

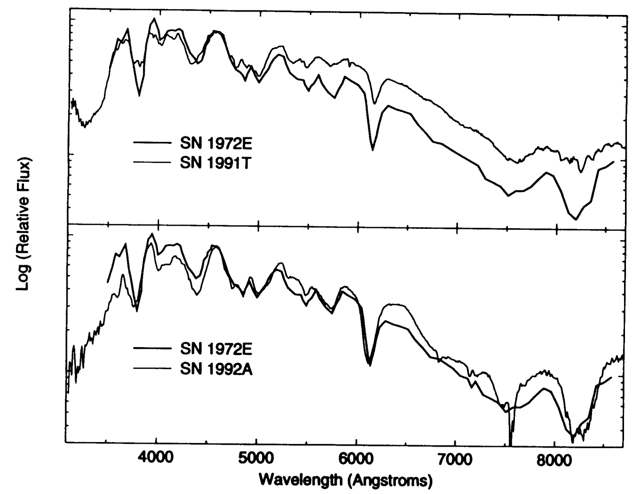

FIG. 3.—*Upper panel:* comparison of spectra of SN 1972E (Branch & Tull 1978) and the peculiar SN 1991T (Filippenko et al. 1992), both obtained 6 days after maximum light. Note the weaker Si II absorption near 6150 Å and the weaker Ca II absorption near 3800 Å in SN 1991T. *Lower panel:* comparison of spectra of SN 1972E and the spectroscopically normal SN 1992A (Kirshner et al. 1993), both obtained 6 days after maximum light. The Si II absorption near 6150 Å and the Ca II absorption near 3800 Å in SN 1972E resemble those of SN 1992A.

SNs Ia, while $\beta_V = 5.0$ makes SN 1972E a slow decliner like SN 1991T. The β_V difference of 1.1 ± 0.5 between SNs 1972E and 1937C implies that SN 1972E may have been brighter in absolute magnitude than SN 1937C by 0.35 ± 0.16 mag. Then the predicted distance modulus for SN 1972E would become $\mu = 28.58 \pm 0.23$ ($D = 5.2 \pm 0.6$ Mpc). We view this result with some suspicion because it is not clear that the linear $M_V - \beta_V$ relation should be used for a spectroscopically normal SN Ia having $\beta_V = 5.0$. Unlike SN 1972E, SN 1991T had an excess of iron-peak elements at the expense of silicon and calcium in its outer layers (Jeffery et al. 1992) which could be responsible, through ^{56}Ni decay, for an especially high luminosity. The immediate postpeak spectra of SN 1972E (Kirshner et al. 1973; Branch & Tull 1978) did not show the spectroscopic peculiarities (weak Si II and Ca II lines) of SN 1991T (Filippenko et al. 1992; Phillips et al. 1992b). This is illustrated in Figure 3, which shows that spectroscopically SN 1972E was more like SN 1992A than like SN 1991T. Additional comparisons, using spectra of lower resolution, lead us to think that SN 1972E closely resembled the spectroscopically normal SN 1981B.

4. CONCLUSION

If the absolute magnitudes of SNs 1937C and 1972E were identical, the difference in their extinction-free apparent magnitudes indicates that the distance modulus of SN 1972E is 0.13 ± 0.14 mag less than that of SN 1937C, that is, $\mu = 28.23 \pm 0.17$ ($D = 4.4 \pm 0.4$ Mpc). If, as suggested by the difference in the post-peak declines of the V-band light curves, SN 1972E was intrinsically brighter than SN 1937C by 0.35 ± 0.16 in M_V, then the distance modulus of SN 1972E would be $\mu = 28.58 \pm 0.23$ ($D = 5.2 \pm 0.6$ Mpc). For the reason given above, we expect the first estimate to be the more accurate.

Our favored distance to SN 1972E of $D = 4.4 \pm 0.4$ Mpc agrees with $D = 4.6 \pm 0.7$ Mpc derived by Della Valle & Melnick (1992) for NGC 5253 from a relation between velocity dispersion and integrated Hβ luminosity for giant H II regions, is consistent within errors with $D = 3.6 \pm 0.9$ Mpc from planetary nebula luminosity functions (G. Jacoby 1993, private communication), but is not consistent with $D = 2.63 \pm 0.12$ Mpc from surface brightness fluctuations (Phillips et al. 1992a). If the Cepheid-based distance to NGC 5253 proves to be near $D = 4.4$ Mpc, the precept that normal SNs Ia are good standard candles, and the corollary that H_0 is low, near 50 km s^{-1} Mpc^{-1}, will receive strong support.

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